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A Case for Good Defaults: Pitfalls in VANET Physical Layer Simulations

Bastian Bloessl* and Aisling O'Driscoll†
*CONNECT Center, Trinity College Dublin, Ireland
†Department of Computer Science, University College Cork, Ireland
mail@bastibl.net, a.odriscoll@cs.ucc.ie

***Abstract*—Network simulations are often the first choice to design, test, and evaluate novel applications and protocols for vehicular networks. Aiming for higher realism, simulators become increasingly complex, relying on detailed simulation models that are developed by different communities. With this trend, it also becomes difficult to understand all models in detail and researchers might lack the expert knowledge to parameterize such models properly. In this paper, we identify suboptimal default parameter values for physical layer effects in common simulation frameworks and show how they can negatively impact the results. We also review papers that use said simulation models and highlight that this is not simply a theoretical issue: We found that the majority of the papers simply copy these default parameter values or do not mention physical layer parameters at all. Both cases are clearly problematic. We thus argue that we should focus on reasonable default parameter values just as much as on the functional correctness of simulation models.**

***Index Terms*—Network Simulation, Physical Layer.**

I. Introduction

Vehicular networks are about to revolutionize transportation and, with this, large parts of our society. The ability to communicate is not a mere add-on but a true game changer. Already today, there are many applications for vehicular networks envisioned, which will result in safer driving, increased efficiency, and improved comfort [1]. Also autonomous driving will benefit, as communication between cars will allow the switch from autonomous to cooperative driving [2].

However, the design of vehicular networks was, and still is, a great challenge. Given the diverse environments (e.g., downtown, rural, freeway), high speeds, varying user densities, and the wide range of applications, Vehicular Ad Hoc Networks (VANETs) require application-specific technologies throughout the network stack.

To design, test, and evaluate these technologies, researchers rely heavily on network simulations, as they allow evaluation of large-scale scenarios in a fast and reproducible manner. Despite these advantages, network simulations also come with drawbacks: While it is trivial to produce *some* results, it is a major challenge to convince fellow researchers that they are realistic and trustworthy. The credibility of simulation studies depends heavily on the underlying simulation models, which (1) have to be well-tested and (2) used with a suitable parameter set. While this is true for any simulator, it is particularly challenging for VANET simulations, as they have to combine knowledge from different fields. This includes models for driving behavior, signal propagation, and networking protocols.

In this paper, we focus on the physical layer, in particular the noise and sensitivity parameters, as default parameter values in popular network simulation frameworks – we look at Veins (v4.7.1) and Artery (as of November 2018) – appear to be suboptimal. While, technically, one could differentiate between a *sample* parameter value, used in an example, and a *default* parameter value, set in the simulation model, we show that this distinction does not matter in practice: both types of parameters are adopted by researchers in a similar fashion.

Studying the impact of these parameters, we make some interesting observations that show that the noise level used in sample simulations leads to a very optimistic communication range beyond 3 km. Furthermore, the combination with the sensitivity level adopted in the same simulations leads to frames with a Signal to Noise Ratio (SNR) of up to 21 dB to be dropped. This is, however, a level where all but the highest modulation and coding scheme work reliably.

Ideally, this would not be a big deal, since every researcher should take care of parameterizing the models as needed. However, this is not what is happening in practice. As simulations get more complex a paper cannot cover all details [3]. In fact, VANET simulations have reached a level of complexity where only a few people fully understand all details – and researchers interested in novel applications might simply lack the expertise to configure and parameterize physical layer models.

In fact, a look at the literature suggests many researchers copy the default parameter values or do not mention the parameters in their work – possibly because they are not directly related with the aspects that are the focus of the study. We, therefore, argue that network simulators should focus on good default parameters just as much as the functional correctness of the simulation models.

Overall, our contributions can be summarized as follows:

- We identify suboptimal default parameter values and misleading parameter names in popular physical layer simulation models.
- We point out the impact on simulation results by comparing the parameters to an improved, more realistic configuration, which we suggest for use as new default parameters.
- We review published works to show that this is a problem in practice, as default parameters are widely adopted for conducting research in the literature.

II. Related Work

When working on new communication protocols, network simulations are often the primary means for performance evaluation. Theoretical evaluations usually require many assumptions to become analytically tractable, while real-world experiments require a working prototype and are laborious and sometimes costly to conduct on a large scale. Network simulations, in turn, allow researchers to evaluate large-scale effects in a fast and reproducible manner. With the proliferation of PCs, simulations found wide adoption in telecommunications research [4].

At least on first thought, the execution of a simulation study might sound like a programming exercise. Yet, there is much more to it than plain implementation, i.e., it is more than turning a protocol or application into a simulation model. The complexity and the science that is behind the topic is well captured in the definitive book about simulative performance evaluation by Law and Kelton [5]. It provides a comprehensive treatment of the topic, highlighting the scientific challenges throughout the whole process from modeling, to simulation, and analysis.

The fact that the challenges outlined by Law and Kelton are not just academic but lead to real problems became clear around 2002 though the seminal work of Pawlikowski et al. [4], which fueled the discussion around the credibility of simulation studies. The authors conducted a systematic review of over 2200 papers published at top tier conferences and journals to point out the problems with random number generation and result evaluation. They showed that the stochastic nature of the simulation models was not considered when evaluating the simulation results. The identification of common problems in published works resulted in what is often referred to as the credibility crisis of network simulations.

Today, the issues with simulation techniques are mostly overcome and the focus of the debate has shifted. The credibility of scientific publications is now often discussed in the context of Open Science. This is a broad concept, which wants to open the whole research process from the planning to the publication phase. Here, Open Source is an important pillar. In this area, enormous progress has been made during the last number of years, with the most popular network simulators released under Open Source licenses [6], [7]. With these simulators, we have a common set of simulation models that are wide-spread and well validated. A remaining issue is that not all papers mention the utilized simulation models [7].

Apart from the functional correctness of the simulation models, the scenarios have a major impact on the results. The community recognized that a common set of standard scenarios is required to compare results between papers. To this effect, the 2015 iteration of the IEEE Vehicular Networking Conference, one of the premier venues for the topic, honored an Open Source traffic simulation model for Luxembourg with the best paper award [8]. The fact that this scenario is adopted in several simulation studies is a great contribution towards reproducibility and comparability of simulation studies.

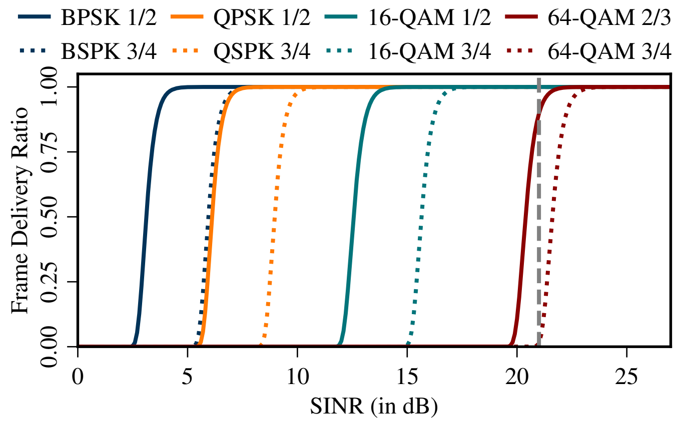


Figure 1. Frame Delivery Ratio according to the NIST error rate model for a 500 Byte frame. The dashed, vertical line corresponds to an SINR of 21 dB, the decoding threshold used in sample simulations of common network simulation frameworks.

Given the increasing complexity of both the simulators and the scenarios, experts recognize the infeasibility of describing a simulation study in a paper. They recommend that in addition to the simulation models and the scenario, input data (i.e., input traces and training data) should also be shared [3]. We fully agree with this recommendation and argue in a similar direction. Here, we focus on the choice of parameters but give concrete results, showing that (1) often important parameters are not mentioned or (2) suboptimal default parameter values are adopted in published simulation studies.

III. Physical Layer Simulation Model

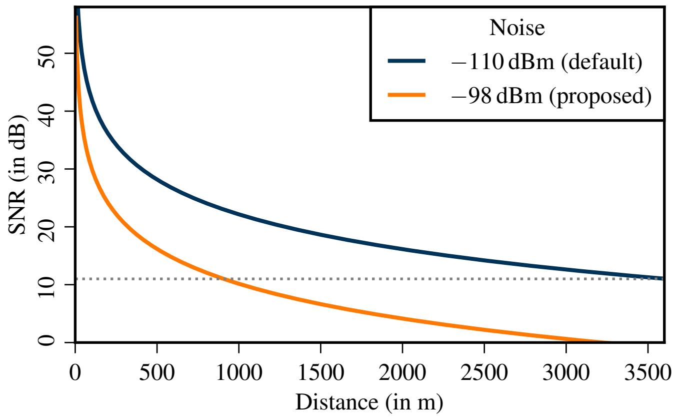
Simulating the physical layer is a great challenge: Given the fact that we cannot directly perceive electromagnetic waves and since the wireless channel is inherently probabilistic, we sometimes lack an intuitive understanding. Furthermore, many researchers who use network simulations have a computer science background, which means that receiver design and channel modeling is not necessarily their area of expertise.

This can lead to problems in practice, especially since simulation of the physical layer requires diverse knowledge, as many models have to be used. This includes models for antennas, the wireless channel, and an error rate model that has to be able to cope with varying signal levels and interference.

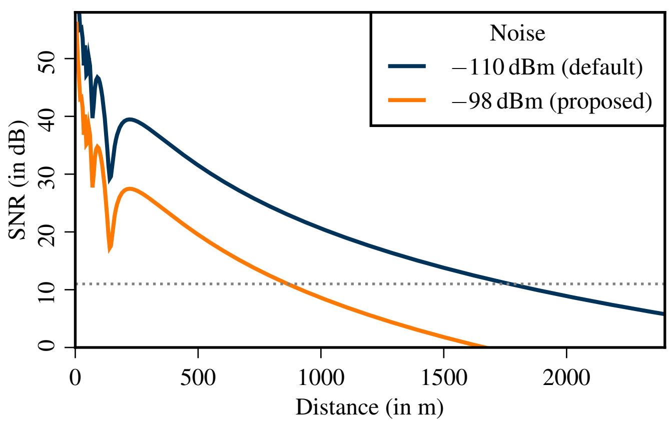
Here, many simulators rely on the NIST error rate model [9]. This model is analytically derived and was validated in a testbed with commercial WLAN cards. While it was validated for 20 MHz, it is also used for 10 MHz configurations.

In essence, the model maps SINR, encoding, and frame size to a probability that an incoming frame is successfully received, i.e., the Frame Delivery Ratio (FDR). The SINR, in turn is calculated as a function of the signal power S and the combination of noise N and the superposition of the n interfering signals I as

$$\text{SINR} = \frac{S}{N + \sum_{i=1}^{n} I_i}. \tag{1}$$



(a) Free-space propagation.



(b) Two-ray interference.

Figure 2. Impact of the noise setting on the SNR at different distances for a 20 dBm signal at 5.89 GHz.

An implicit assumption of this calculation is that noise and interference have a similar effect on the physical layer performance. A systematic study showed that this is a reasonable assumption [10]. A minor complication is that the SINR might change during the reception of the frame.

There are two ways to deal with this. Veins and Artery rely on a computationally efficient, conservative estimate by using the minimum SINR for the calculation of the FDR. Ns-3, on the other hand, groups the frame in chunks with similar SINR, calculates the error rate for each chunk, and uses it calculate the error rate for the whole frame.

Exemplary error curves for the NIST error rate model of 500 Byte frames are shown in Figure 1. It shows the FDR for all modulation and coding schemes for different SINRs. The dashed vertical line corresponds to an SINR of 21 dB, which has an important relevance in the following paragraphs.

IV. Impact of Noise

From Equation (1), we can see that noise plays an important role for physical layer performance. There are multiple noise sources in a receiver – with the most important ones being the thermal noise and the noise figure of the device. Thermal noise depends on the bandwidth of the signal and the temperature of the environment. Since we are not operating at absolute zero, the electrons in the antenna are not fixed, creating small random currents that superimpose the received signal. The higher the temperature, the higher the movements and, thus, the average power of the current. Usually, this is modeled as white noise with a flat power spectrum. The rationale is that the current is the sum of many independent electron movements and, therefore, uncorrelated and normally distributed. This means that, no matter how fast we sample, we always get an uncorrelated value. The amount of thermal noise that is in the system depends on the bandwidth of the signal. The 10 MHz signal of IEEE 802.11p, for example, has to be sampled with at least 10 MHz, pulling at least 10 MHz of noise into the system.

In addition to thermal noise, we have to consider the noise figure of the device. Due to non-idealities in the analog frontend of the receiver, the signal quality is degraded. These imperfections introduce additional noise, which is referred to as the noise figure of the device. The noise figure of the MAX2828 IEEE 802.11a transceiver chip, for example, is between 4 dB and 8 dB depending on frequency and gain settings [11]. This matches well with the noise figures of SDRs from Ettus Research and the ns-3 default of 7 dB.

Veins and Artery, in turn, lump all influence of noise together as one parameter and adopt a value of −110 dBm in sample simulations. This value, however, is beyond optimistic: it is below physical limitations for a 10 MHz signal, which would result in a thermal noise of −104 dBm at room temperature. This 6 dB deviation of the thermal noise (in addition to the impact of a noise figure) can indeed have a major impact on the results. If we consider, for example, a noise figure of 6 dB, it results in a shift of the error curves by 12 dB in total. The impact of this change is shown in Figure 2a, where we plot the SNR for a 20 dBm signal at 5.89 GHz under free-space propagation. As we can see, the different noise settings are reflected through a shift of the curve along the y-axis. The horizontal, dotted line corresponds to an SNR of 11 dB, which, as can be seen in Figure 1, is the level where 500 Byte BPSK and QPSK frames are received reliably. For these frames the range decreases considerably, the 11 dB range reduces from 3600 m to 900 m with the more realistic parameter values.

One might argue that the results for free-space are not interesting in vehicular scenarios as the model is typically combined with further models to account for shadowing or multi-path fading. The two most common examples are the obstacle shadowing model [12] and the two-ray interference model [13]. The obstacle shadowing model is a geometric model that considers signal attenuation through buildings. Along the street, it does not attenuate the signal. That is on purpose, since it is a pure shadowing model that has to be combined with other models. For example with the free-space or two-ray interference model, which considers an additional ray from reflections on the street. For close distances its attenuation oscillates around the free-space path loss, while for larger distances it exhibits a stronger attenuation. The impact of the noise setting on the two-ray model is shown in Figure 2b. Using the parameters from the previous experiment, i.e., a 20 dBm signal at 5.89 GHz, the 11 dB range still changes considerably. In this case, it decreases from 1775 m to 865 m.

V. Impact of Sensitivity Definitions

Another important parameter of the physical layer simulation model is sensitivity. The core issue with sensitivity is that there is no general definition of the term. In the context of the IEEE 802.11 standard, it is defined as the receive power level above which a 1000 Byte frame has to be decoded with a probability of at least 90 % [14], i.e., it defines a signal level where the receiver has to operate rather reliably. Furthermore, there is not *the* sensitivity of a receiver but one minimum sensitivity for each modulation and coding scheme.

Exemplary values of BPSK and QPSK for 10 MHz and 20 MHz channels are shown in Table I. Considering a 10 MHz channel, the interpretation is that a 1000 Byte BPSK-½ frame that is received with a power level of −85 dBm or above has to be decoded in at least 90 % of the cases. We included the table to highlight the relationship of the signal bandwidth, sensitivity, and noise: If we compare an otherwise similar 20 MHz frame with a 10 MHz frame, we have a signal with the same power but half the bandwidth. Cutting the bandwidth in half also cuts the noise bandwidth in half and effectively doubles the SNR. In logarithmic scale, this corresponds to an SNR improvement of approximately 3 dB. Consequently, the sensitivity values of 10 MHz and 20 MHz channels differ by 3 dB.

Another implication of the IEEE 802.11 definition of sensitivity is that it is not well-suited as a parameter for a physical layer simulation model. Rather it is an indirect result of the noise in combination with the error model, which does the mapping from the frame size, SNR, and modulation and coding scheme to the FDR.

For hardware vendors, this definition can be used as a quality indicator for their products: The Cohda Wireless MK5 OBU, a popular IEEE 802.11p prototype, for example, offers a sensitivity of −99 dBm for BPSK-½, surpassing the minimum requirement of IEEE 802.11 by 14 dB.

The definition in Veins and Artery is totally different. Here, a parameter called *sensitivity* defines the minimum receive power level at which an attempt is made to decode a frame. If we would map the semantic of this parameter to a real-world receiver, it would correspond to the minimum power level that is required to detect the frame, i.e., to recognize its preamble. Thus, the term *sensitivity* is somewhat of a misnomer in these simulation frameworks. Sample simulations of Veins and Artery have this threshold configured to −89 dBm. This parameter setting in combination with the same simulations' noise level of −110 dBm means that frames with an SNR of up to 21 dB are not considered for decoding. Cross-checking this SNR with the error curves from Figure 1 reveals that this is an unfortunate parameter setting. At 21 dB (indicated by the dashed vertical line), all but the most complex modulation schemes already work reliably. As a result, frames that would be decoded with 100 % reliability are ignored by the receiver. They only contribute to the interference level.

Table I
Receiver performance requirements (from [14, Table 17-18]).

Encoding	Minimum Sensitivity (20 MHz)	Minimum Sensitivity (10 MHz)
BPSK-½	−82 dBm	−85 dBm
BPSK-¾	−81 dBm	−84 dBm
QPSK-½	−79 dBm	−82 dBm
QPSK-¾	−77 dBm	−80 dBm

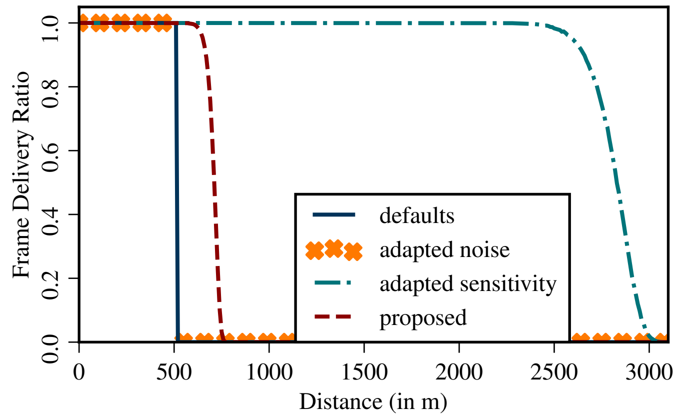


Figure 3. FDR at different distances depending on the configuration. The sample simulation (noise = −110 dBm, sensitivity = −89 dBm) and the case where only noise is adapted results in the same graph. The proposed configuration is where both parameters are adapted (noise = −98 dBm, sensitivity = −98 dBm).

To show this effect, we used the popular simulation framework Veins in its current version (v4.7.1) to conduct simulations with different parameter combinations. We used two nodes and varied their distance. One node sent 500 Byte QPSK-½ frames on channel 178 at 5.89 GHz with a transmit power of 20 dBm. The channel model was simple free-space propagation, which allows us to focus on the impact of the discussed parameters. In each experiment, we sent 2000 frames and recorded the FDR. Since only one station sent frames, there were no collisions or backoffs. Each experiment was repeated 10 times. The resulting FDR measures exhibited close to zero variance, which led to very small confidence intervals. We, therefore, omitted them in Figure 3, where we plot the FDR with different parameter combinations for noise and sensitivity. The noise was varied between the default parameter value of −110 dBm and our proposed value of −98 dBm with the sensitivity varied between the default parameter value of −89 dBm and a value of −110 dBm. The latter value was chosen such that there is at least an attempt to decode frames with an SNR of zero, even with the low default noise value. This is still a conservative choice, since frame detection works very reliably for an SNR of zero [15]. In general, it is our view that the sensitivity threshold should be set to a value around the noise floor to ensure that no decodable frames are dropped (cf. Figure 1). Note that at the moment, there is another limitation of the simulation framework that prohibits setting the value arbitrary low: Veins does not implement frame capturing, which means that once the receiver synchronizes on a frame, it will stick to this frame irrespective of whether another frame with a higher power is incoming. By setting the value for the sensitivity too low, the receiver would synchronize on undecodable low-power frames and, in effect, become deaf for any other frames. A real IEEE 802.11p receiver, in turn, can resynchronize on an interfering high-power frame.

In Figure 3, we can see that using the default simulation parameter values lead to a rough cut off connectivity at about 500 m. This is the point where the signal power falls below the sensitivity threshold and the frames are ignored. The immediate transition from full reliability to zero reliability shows that the default simulation parameters, in essence, degrade to a unit-disk propagation model. If we lower the sensitivity and also consider these frames, we reach distances of up to 3000 m, which is a 500 % increase. (Note, that for this setting, we also had to increase the default interference distance of 2600 m. Otherwise, the simulator does not forward the frame to the receiver, which leads to another hard cutoff at this distance.) If we only increase the noise to the proposed value of −98 dBm but leave the sensitivity at that of the sample simulation, the result remains unchanged. This is because the signal drops below the sensitivity threshold at the exact same distance. The only difference is that the SNR at this particular cutoff point is 9 dB instead of 21 dB. Yet, as even this SNR results in perfect reliability (cf. Figure 1), the result is the same degraded curve. Finally, the proposed parameter set with adapted sensitivity and noise is depicted by the dashed line. It drops smoothly at about 750 m, which is a 50 % increase with regard to the default simulation parameters.

Besides the significant differences in physical layer performance, the default parameter values might also motivate incorrect conclusions. One could, for example, underestimate the impact of interference: Due to the high sensitivity in combination with the low noise, a frame has a lot of room for interfering signals once it surpasses the sensitivity threshold. For that reason, the physical layer could wrongfully appear very robust against interfering signals. The performance differences between modulation and coding schemes could be misinterpreted for a similar reason. A frame that is above the sensitivity threshold has a high SNR and can likely be decoded independent from the modulation and coding scheme. The impact of the encoding might, therefore, be underestimated.

VI. Impact on Vehicular Network Simulations

The impact of the noise and sensitivity on the physical layer performance has been shown to be significant. We think that it is clear that, depending on the simulation setup and target metrics, this can also be visible in the results and, therefore, might impact the outcome and interpretation of a simulation study. In this section, we shift our focus from the impact on the result to the impact on published research, i.e., we look into how the physical layer simulation model is used in practice. At the time of writing (November 2018), Veins lists over 630 papers that use it on its website.[1] We selected the 20 most recent journal papers that use IEEE 802.11p to check for noise and sensitivity parameters. For each parameter, the paper can (1) use the default parameter values, (2) use an adapted value, or (3) not mention the parameter at all.

The results are quite worrying: Only one out of the 20 papers refers to the noise level. It used the default parameter value of −110 dBm. Sensitivity, in turn, was mentioned by three papers, all of which are using the default parameter value of −89 dBm, which in combination with the noise ignores frames up to an SNR of 21 dB, as discussed earlier. While this is only a brief review of the literature, we believe that it is enough to highlight that there is an issue. We continued with a non-systematic review and, indeed, found papers that used calibrated parameter values, but the vast majority used the default parameter values or did not mention the parameter(s) at all.

The reason for this situation is probably that most works focus on applications or higher-layer protocols and, therefore, do not have an in-depth look at the physical layer. The fact that important parameters are not mentioned suggests that the simulation model is used as a black box. This is clearly a suboptimal situation, which might result from the fact that simulations have reached a level of complexity, where it has become difficult to have a detailed understanding of all models. We believe that it is important for the research community to have a discussion on how to deal with this. A pressing question is how to deal with parameters that are not mentioned. Should we assume that they were set to reasonable values? Should we assume that they were unimportant for the results of the paper or that they were not considered and instead copied from default parameter values? Of course, Open Science could be a step in the right direction, but it assumes that the reviewers have the time and expert knowledge to evaluate a simulation study (including the source code for the simulation models, the scenario, and the results evaluation). Network simulators, in turn, could try to create simulation models that can be used as a black box, but this is not always possible and might motivate researchers to deal even less with simulation models. We do not think that there is an easy solution but wish to raise awareness of the issue and highlight the importance of good default parameter values and examples.

As an intermediary step towards widespread dissemination of the insights reported in this paper, we have reached out to the maintainers of Veins, the popular simulation framework used for generating the results discussed in this paper. This has resulted in the documentation of its physical layer parameters being updated and all of its sample simulations being adapted to use the parameter values recommended by us.

VII. Conclusion

Conducting simulation studies is a great challenge. This is particularly true for VANETs, a subject at the intersection of many fields with simulation models developed by different communities. As a result, not every researcher is necessarily

[1] http://veins.car2x.org/publications/

an expert in all aspects of the network stack and, therefore may not be familiar with the details of the employed models. In this paper, we put the focus on the physical layer and highlighted the impact of suboptimal choices for default parameter values with respect to noise and sensitivity parameters. Through theoretic evaluations and simulations, we compared the default parameter values with a proposed configuration and observed huge differences. We also showed that this is not a minor usability problem but a real issue in practice, since the default parameter values are widely adopted in published simulation studies. While this has been addressed in the case of one simulation framework, this only addresses the problem going forward – and only for this one simulator. The goal of this paper is to highlight this issue and motivate a discussion about how to deal with the ever increasing complexity of simulation studies.

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